Scintillating sampling ECAL technology for the LHCb PicoCal

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Motivation

- After LS4 (2033/2034) of LHC, higher luminosity and higher pile up set demands on ECAL of LHCb
- Enhancement of ECAL already planned for LS3

LS3

Radiation damage of inner region of ECAL → SPACAL & rhombic shape

LS4

Sustain **1 MGy** radiation doses

Mitigate high **pile up**

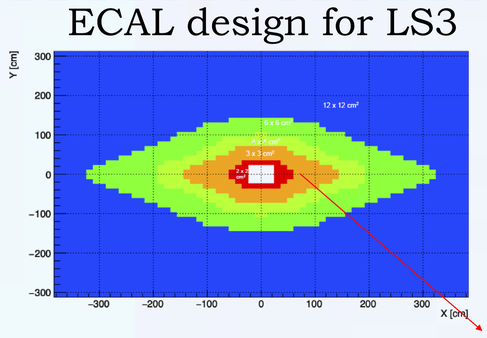
Keep current energy resolution, $\boldsymbol{\sigma_E/\sqrt{E} = 10\%/\sqrt{E}\oplus 1\%}$

Timing information, with resolution $\mathcal{O}(10\,ps)$

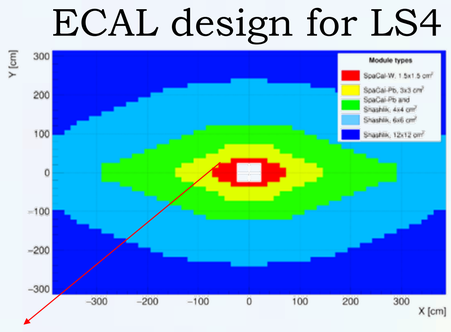
SPACAL & rhombic shape & Double side readout

High granularity structure

ECAL design for LS3

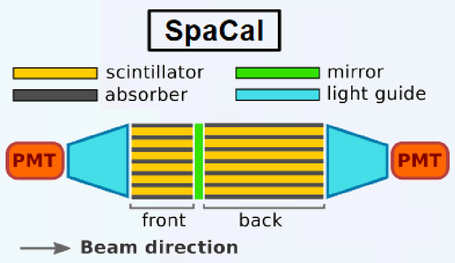


ECAL design for LS4

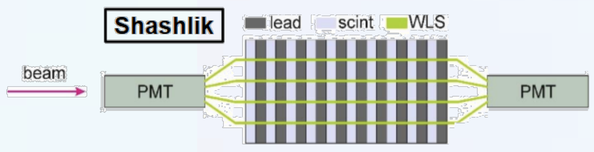


Inner region (red orange in the left, red yellow in the right) replaced with SPACAL

Technology



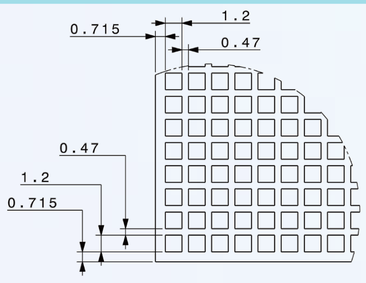
Absorber	Tungsten (W)		Lead (Pb)
Installation	LS3	LS4	LS3/4
Fibres	Polystyrene	GAGG	Polystyrene
Cell Size	2×2 cm^2	1.5×1.5 cm^2	3×3 cm^2
Moliere radius	1.8 cm	1.46 cm	≈ 3 cm

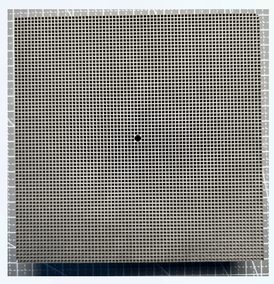


- Timing capability
- Double side readout
- WLS fibres replaced

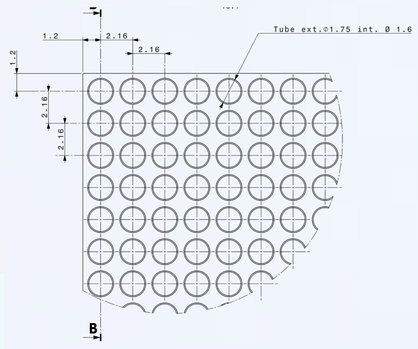
Absorber and crystal for SPACAL

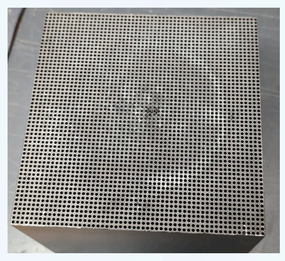
Tungsten absorber
- Hole: 1.2×1.2 mm^2
- Pitch: 1.67 mm
- 5041 holes
- 3D printing

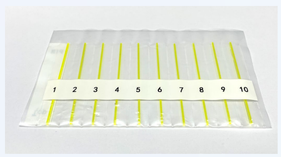


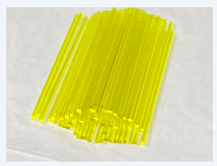


Lead absorber
- Hole diameter: 1.6 mm
- Pitch: 2.16 mm
- 3136 holes
- Low pressure casting





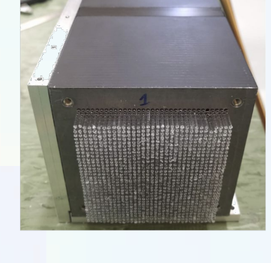




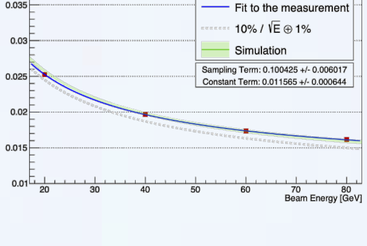
GAGG
- Active R&D ongoing
- Size: $1.0 \times 1.0 \times 50(100)$ mm^3

Testbeam results

Tungsten + Garnet crystal

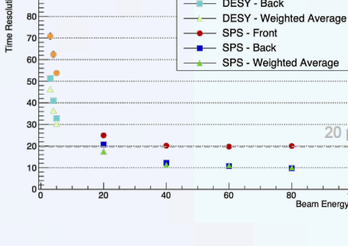


Energy resolution (DESY 2020, R12421)



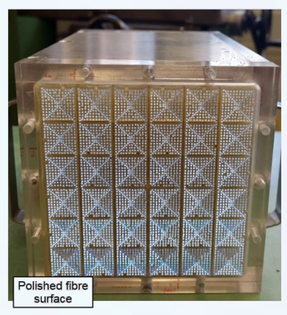
Sampling term : 10.2%
Constant term : 1%-2%

Time resolution (DESY 2021, R7600U-20)

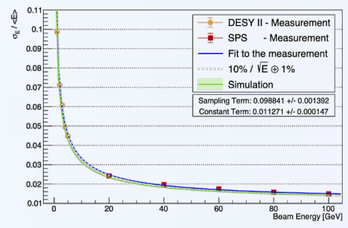


Time resolution at 5 GeV for GFAG: better than 20 ps

Lead + polystyrene

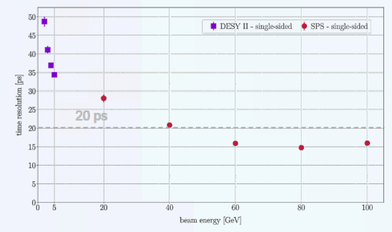


Energy resolution (DESY & SPS, R14755U-100)



Sampling term : 9.9%
Constant term : 1.1%

Time resolution (DESY & SPS, R7600U-M4)



Time resolution above 40 GeV : better than 20 ps

Lead + polystyrene

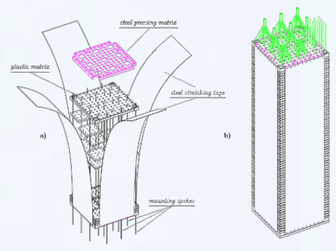
Energy resolution (CERN SPS)

Sampling term : 10%
Constant term : 1.16%

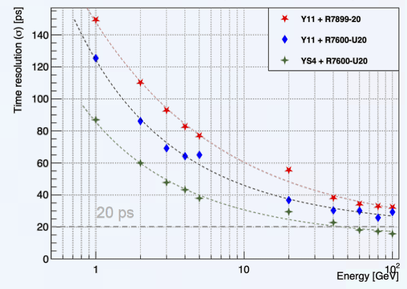
Time resolution (DESY & SPS, R11187)

Time resolution above 20 GeV: better than 20 ps

Shashlik



Time resolution (DESY and SPS)



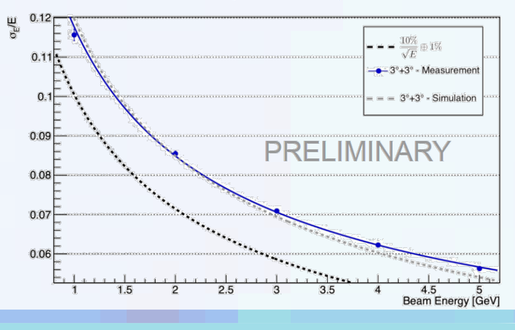
Time resolution above 40 GeV: better than 20 ps

- Energy resolution: Good sampling term (~10%) and constant term (~1%) achieved
- Time resolution: $\mathcal{O}(10\,ps)$ time resolution achieved

Simulation results

- Geant4 simulation with parametrised propagation of scintillating photons
- Simulation results agree with test beam results with for Pb-polystyrene

Measurement, DESY, 2 mm fibres



Summary

LS3
- Inner modules of LHCb ECAL need to be replaced during LS3 due to radiation damage
  - SPACAL technology (W/Pb absorbers) meets the requirements

LS4
- Picosecond-level timing capability and more demanding radiation hardness requirements during LS4
  - $\mathcal{O}(10\,ps)$ time resolution achieved for shashlik and SPACAL technology
  - SPACAL with W/Pb absorbers and crystal/Polystyrene fibres for central region

R&D ongoing
- Test beam with prototypes
- Monte Carlo simulations
- Novel absorber production techniques
- New radiation hard and fast scintallators
- Suitable PMTs and readout electronics

Reference: LHCB-TDR-023 & LHCb-TDR-24 &
Nuclear Inst. and Methods in Physics Research, A 1045 (2023) 167629